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APPLICATION FOR LETTERS PATENT

Title :METHOD FOR MANUFACTURING SEMICONDUCTOR
DEVICE

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CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2003-074381, filed on March 18, 2003, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[Field of the Invention]

The present invention relates to a method for manufacturing a semiconductor device suitable for the formation of a wiring layer.

[Description of the Related Art]

Recently, with a request for miniaturization, a damascene method is often adopted in manufacturing a semiconductor device. Moreover, in the damascene method, in terms of CMP (Chemical Mechanical Polishing) of a wiring material and photolithography technology, three-layer structured hard mask is sometimes used when a via hole and a wiring trench are formed in an interlayer insulating film. This is for the following reason.

Fig. 4A to Fig. 4C are sectional views showing the progress of CMP in the damascene method step by step. When a porous silica film 114 as an interlayer insulating film is formed and a wiring trench is formed in this porous silica film 114, an insulating film 115 which prevents the porous silica film 114

from being polished and an insulating film 116 as a polishing allowance in CMP are needed. In order to perform CMP with high precision, that is, in order to enable the thickness of each film to be a designed value, the insulating film 115 is required to have high hardness, and the insulating film 116 is required to be polished by CMP more easily than the insulating film 115. Hence, a SiC film, a SiN film, a SiOC film with high hardness, or the like is used as the insulating film 115, and an SiO₂ film or the like is used as the insulating film 116. By using these films, when CMP is performed as shown in Fig. 4B after a Cu film 117 is embedded in the wiring trench as shown in Fig. 4A, the CMP is stopped at the surface of the insulating film 115 as shown in Fig. 4C.

When the SiO₂ film is used as the insulating film 116, a selection ratio between the insulating film 116 and the porous silica film is low. Therefore, the insulating film 116 needs to be relatively thick. However, in the case of such a two-layer structured hard mask as shown in Fig. 4A to Fig. 4C, it is impossible to thicken the insulating film 116. This is for the following reason.

Fig. 5A and Fig. 5B are sectional views showing the progress of etching with an ArF resist step by step. For example, as shown in Fig. 5A, an antireflection film 120 such as an BARC (Bottom Anti-

Reflection Coating) is formed on a film to be processed 119 such as the insulating film 116, and a resist mask 121 made of the ArF resist is formed on the antireflection film 120. Then, the antireflection film 120 and the film to be processed 119 are etched with the resist mask 121 as a mask. Since the ArF resist has low resistance to etching at this time and thereby the resist mask 121 becomes thinner, the processable depth of the film to be processed 119 is shallow. Further, recently, with a request for miniaturization, it becomes necessary to reduce the thickness of the resist mask 121 in order to improve resolution. Hence, the depth of the film to be processed 119 which can be processed with the resist mask 121 becomes shallower.

In these circumstances, it is impossible to thicken the insulating film 116 in the case of the two-layer structured hard mask. Hence, a three-layer structured hard mask is used by further forming a thin hard mask on the insulating film 116.

Prior arts are disclosed in Japanese Patent Laid-open No. 2000-351976, Japanese Patent Laid-open No. 2001-77196, and Japanese Patent Laid-open No. 2002-222860.

However, it has become difficult to cope with further miniaturization even if the three-layer structured hard mask is used. Fig. 6A to Fig. 6D are sectional views showing a method for manufacturing a

semiconductor device, which adopts a conventional damascene method, step by step.

In the conventional manufacturing method, as shown in Fig. 6A, a SiC film 103, a porous silica film 104, a SiC film 105, a SiO₂ film 106, a SiN film 107, and an antireflection film 109 such as an BARC are formed in sequence on a Cu wiring 102, and thereafter a resist mask 110 made of an ArF resist is formed.

Then, as shown in Fig. 6B, the antireflection film 109 and the SiN film 107 are etched with the resist mask 110 as a mask. Subsequently, the resist mask 110 is removed by ashing.

Thereafter, as shown in Fig. 6C, the SiO₂ film 106 is etched with the SiN film 107 as a mask. Then, the SiC film 105 is etched with the SiO₂ film 106 as a mask, and simultaneously the SiN film 107 is removed.

Subsequently, as shown in Fig. 6D, the porous silica film 104 and the SiC film 103 are etched with the SiO₂ film 106 as a mask. Thereafter, a wiring is formed.

In the aforementioned conventional manufacturing method, as shown in Fig. 6D, a selection ratio between the SiO₂ film 106 and the inorganic porous silica film 104 is low, whereby an end portion of the SiO₂ film 106 used as the hard mask is rounded off. As a result, the size of an opening becomes larger

than a designed value, which easily causes leakage between adjacent wirings.

To avoid the aforementioned drawback, it is conceivable to thicken the SiO_2 film 106, but to thicken the SiO_2 film 106, it is also necessary to thicken the SiN film 107 used as a hard mask when the SiO_2 film 106 is patterned, which causes a problem regarding photolithography.

If the SiN film 107 is thickened, the following problem arises. Fig. 7A to Fig. 7C are sectional views showing a method for forming a resist mask by a dual damascene method step by step.

In a trench-first exposure type dual damascene method, as shown in Fig. 7A, a hard mask 123 on which a wiring trench pattern is formed is formed on a film to be processed 122, and thereafter, as shown in Fig. 7B, a resist mask 124 made of an ArF resist is formed on the entire surface. At this time, the resist mask 124 in a portion on which a wide wiring trench pattern is formed is thinner than that in other portions. Then, when a via hole pattern is formed on the resist mask 124 by exposure and developing as shown in Fig. 7C, the size of the via hole becomes larger than a designed value in the portion where the resist mask 124 is thinner.

Moreover, as described above, to improve the resolution, it is necessary to reduce the thickness

of the resist mask, whereby the top-layer hard mask needs to be thin.

SUMMARY OF THE INVENTION

The present invention is made in view of the aforementioned problem and its object is to provide a method for manufacturing a semiconductor device capable of preventing leakage between wirings caused by miniaturization.

As a result of assiduous studies, the inventor of the present invention has reached various aspects of the invention described below.

A method for manufacturing a semiconductor device according to the present invention aims at a method for manufacturing a semiconductor device having the step of forming a wiring by a damascene method. In this manufacturing method, an etching stopper film and an interlayer insulating film are formed in sequence over a conductive layer. Then, a silicon carbide film, a silicon nitride film, or a silicon oxynitride film is formed as a first hard mask over the interlayer insulating film. Subsequently, a silicon oxide film is formed as a second hard mask over the first hard mask. Thereafter, a silicon carbide film or a silicon nitride film is formed as a third hard mask over the second hard mask. Then, a silicon oxide film is formed as a fourth hard mask over the third hard mask. Subsequently, a pattern is

formed over the fourth hard mask. Thereafter, the third hard mask is etched with the fourth hard mask. Then, the second hard mask is etched with the third hard mask. Subsequently, the first hard mask is etched with the third hard mask. Then, an opening which reaches the etching stopper film is formed in the interlayer insulating film by etching the interlayer insulating film with the third hard mask. Thereafter, a portion of the etching stopper film which is exposed from the opening formed in the interlayer insulating film is etched. Subsequently, a wiring material is embedded in the opening.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A to Fig. 1J are sectional views showing a method for manufacturing a semiconductor device according to a first embodiment of the present invention step by step;

Fig. 2A to Fig. 2N are sectional views showing a method for manufacturing a semiconductor device according to a second embodiment of the present invention step by step;

Fig. 3 is a sectional view showing the structure of the semiconductor device manufactured by applying the second embodiment thereto;

Fig. 4A to Fig. 4C are sectional views showing the progress of CMP in a damascene method step by step;

Fig. 5A and Fig. 5B are sectional views showing the progress of etching with an ArF resist step by step;

Fig. 6A to Fig. 6D are sectional views showing a method for manufacturing a semiconductor device, which adopts a conventional damascene method, step by step; and

Fig. 7A to Fig. 7C are sectional view showing a method for forming a resist mask in a dual damascene method step by step.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A method for manufacturing a semiconductor device according to each of embodiments of the present invention will be concretely described below with reference to the attached drawings.

-First Embodiment-

First, the first embodiment of the present invention will be described. Fig. 1A to Fig. 1J are sectional views showing a method for manufacturing a semiconductor device according to the first embodiment of the present invention step by step. In this embodiment, the semiconductor device is manufactured by a single damascene method.

First, as shown in Fig. 1A, a SiC film 3 as an etching stopper film is formed on a Cu wiring 2 (conductive layer) formed in an interlayer insulating film 1. The thickness of the SiC film 3 is, for

example, 30 nm. Then, a porous silica film 4 as an interlayer insulating film is formed on the SiC film 3. The thickness of the porous silica film 4 is, for example, 200 nm. The porous silica film 4 is a porous low dielectric constant insulating film.

Subsequently, a SiC film 5 as a first hard mask is formed on the porous silica film 4, and then a SiO₂ film 6 as a second hard mask is formed. The thicknesses of the SiC film 5 and the SiO₂ film 6 are, for example, 40 nm and 70 nm, respectively. Thereafter, a SiC film 7 as a third hard mask is formed on the SiO₂ film 6, and then a SiO₂ film 8 as a fourth hard mask is formed. Preferably, the thickness of the SiC film 7 is more than twice that of the SiC film 5, and the SiC film 7 and the SiO₂ film are, for example, 80 nm and 50 nm respectively in thickness. Thereafter, an antireflection film 9 which is necessary for patterning is formed on the SiO₂ film 8. The antireflection film 9 is, for example, an organic BARC. Then, an organic ArF photoresist is applied on the antireflection film 9, and then exposed and developed to form a resist mask 10 on which a wiring trench pattern is formed. The wiring trench width is, for example, approximately 100 nm.

Thereafter, as shown in Fig. 1B, the antireflection film 9 is etched with the resist mask 10 as a mask. In this etching, gas, for example,

containing CF_4 and Ar is used. More specifically, this etching is performed using a plasma etching device, for example, under the condition of 50 sccm of CF_4 , 20 sccm of Ar, 6.67 Pa (50 mTorr) of pressure, and 300 W of RF source power.

Subsequently, the SiO_2 film 8 is etched with the resist mask 10 as a mask. In this etching, gas, for example, containing C_4F_6 is used and the power is relatively high. More specifically, this etching is performed using the plasma etching device, for example, under the condition of 30 sccm of C_4F_6 , 15 sccm of O_2 , 300 sccm of Ar, 4.00 Pa (30 mTorr) of pressure, and 1000 W of RF source power. As a result, the SiO_2 film 8 is patterned in the wiring trench pattern.

Then, as shown in Fig. 1C, the resist mask 10 and the antireflection film 9 are removed by ashing.

Thereafter, as shown in Fig. 1D, the SiC film 7 is etched with the SiO_2 film 8 as a mask. In this etching, in order to raise the selection ratio between the SiO_2 films 6 and 8 and the SiC film 7, gas, for example, containing CHF_3 , CH_2F_2 , or CH_3F and further containing N_2 , O_2 , and Ar is used, and the power is low. More specifically, this etching is performed using the plasma etching device, for example, under the condition of 30 sccm of CH_2F_2 , 20 sccm of O_2 , 50 sccm of Ar, 50 sccm of N_2 , 2.67 Pa (20 mTorr) of pressure, and 200 W of RF source power.

Subsequently, as shown in Fig. 1E, the SiO₂ film 6 is etched with the SiC film 7 as a mask, and simultaneously the SiO₂ film 8 is removed. In this etching, in order to raise the selection ratio between the SiO₂ films 6 and 8 and the SiC films 5 and 7, gas, for example, containing C₄F₆, C₄F₈, C₅F₈, CHF₃, or CH₂F₂ and further containing O₂ and Ar is used, and the power is high. More specifically, this etching is performed using the plasma etching device, for example, under the condition of 20 sccm of C₄F₆, 15 sccm of O₂, 200 sccm of Ar, 4.00 Pa (30 mTorr) of pressure, and 1500 W of RF source power.

Thereafter, as shown in Fig. 1F, the SiC film 5 is etched with the SiC film 7 as a mask. As a result, an exposed portion of the SiC film 5 is removed, and the SiC film 7 is thinned. In this etching, gas, for example, containing CHF₃, CH₂F₂, or CH₃F and further containing N₂, O₂, and Ar is used, and the power is low. More specifically, this etching is performed using the plasma etching device, for example, under the condition of 30 sccm of CH₂F₂, 20 sccm of O₂, 50 sccm of Ar, 50 sccm of N₂, 2.67 Pa (20 mTorr) of pressure, and 200 W of RF source power.

Then, as shown in Fig. 1G, the porous silica film 4 is etched with the SiC film 7 as a mask. Because of the etching, surface roughness tends to occur to the porous silica film, and the porous silica film tends to have a sub-trench shape. Therefore, in this

etching, gas, for example, containing CF_4 is used, and the pressure is high (for example, 6.67 Pa to 40.0 Pa (50 Torr to 300 mTorr)). To prevent side etching, CHF_3 , C_4F_6 , C_5F_8 , or C_4F_8 is further mixed. More specifically, this etching is performed using the plasma etching device, for example, under the condition of 50 sccm of CF_4 , 100 sccm of CHF_3 , 50 sccm of Ar, 10 sccm of N_2 , 26.7 Pa (200 mTorr) of pressure, and 1000 W of RF source power. As a result of this etching, a wiring trench 13 is formed in the porous silica film 4.

Thereafter, as shown in Fig. 1H, an exposed portion of the SiC film 3 and the SiC film 7 are removed by etching. In this etching, gas, for example, containing CHF_3 , CH_2F_2 , or CH_3F and further containing N_2 , O_2 , and Ar is used, and the power is low. More specifically, this etching is performed using the plasma etching device, for example, under the condition of 30 sccm of CH_2F_2 , 15 sccm of O_2 , 50 sccm of Ar, 75 sccm of N_2 , 2.67 Pa (20 mTorr) of pressure, and 150 W of RF source power. As a result of this etching, the wiring trench 13 reaches the lower Cu wiring 2.

Subsequently, as shown in Fig. 1I, a Cu film (wiring material) 11 is embedded in the wiring trench 13, and as shown in Fig. 1J, by subjecting the Cu film 11 to CMP (Chemical Mechanical Polishing), a Cu wiring 12 is formed. Thereafter, an interlayer

insulating film, a wiring, and the like are formed as required to complete the semiconductor device.

According to the aforementioned first embodiment, a hard mask is four-layer structured, and when the porous silica film 4 is etched, the SiC film 7, whose selection ratio to the porous silica film 4 is high, is used as a mask. Therefore, deformation of the hard mask rarely occurs, which can prevent leakage caused by the deformation.

-Second Embodiment-

Next, the second embodiment of the present invention will be described. Fig. 2A to Fig. 2N are sectional views showing a method for manufacturing a semiconductor device according to the second embodiment of the present invention step by step. In this embodiment, the semiconductor device is manufactured by a trench-first exposure type dual damascene method.

First, as shown in Fig. 2A, a SiC film 3 as an etching stopper film is formed on a Cu wiring 2 (conductive layer) formed in an interlayer insulating film 1. The thickness of the SiC film 3 is, for example, 30 nm. Then, a porous silica film 4 as an interlayer insulating film is formed on the SiC film 3. The thickness of the porous silica film 4 is, for example, 400 nm.

Subsequently, a SiC film 5 as a first hard mask is formed on the porous silica film 4, and then a SiO₂

film 6 as a second hard mask is formed. The thicknesses of the SiC film 5 and the SiO₂ film 6 are, for example, 40 nm and 70 nm, respectively. Thereafter, a SiC film 7 as a third hard mask is formed on the SiO₂ film 6, and then a SiO₂ film 8 as a fourth hard mask is formed. Preferably, the thickness of the SiC film 7 is more than twice that of the SiC film 5, and hence the SiC film 7 and the SiO₂ film 8 are, for example, 80 nm and 50 nm respectively in thickness. Thereafter, an antireflection film 9 which is necessary for patterning is formed on the SiO₂ film 8. The antireflection film 9 is, for example, an organic BARC. Then, an organic ArF photoresist is applied on the antireflection film 9, and then exposed and developed to form a resist mask 10 on which a wiring trench pattern is formed.

Thereafter, as shown in Fig. 2B, the antireflection film 9 is etched with the resist mask 10 as a mask. In this etching, gas, for example, containing CF₄ and Ar is used. More specifically, this etching is performed using a plasma etching device, for example, under the condition of 50 sccm of CF₄, 20 sccm of Ar, 6.67 Pa (50 mTorr) of pressure, and 300 W of RF source power.

Subsequently, the SiO₂ film 8 is etched with the resist mask 10 as a mask. In this etching, gas, for example, containing C₄F₆ is used, and the power is

relatively high. More specifically, this etching is performed using the plasma etching device, for example, under the condition of 30 sccm of C_4F_6 , 15 sccm of O_2 , 300 sccm of Ar, 4.00 Pa (30 mTorr) of pressure, and 1000 W of RF source power. As a result, a wiring trench pattern (first pattern) is formed on the SiO_2 film 8.

Then, as shown in Fig. 2C, the resist mask 10 and the antireflection film 9 are removed by ashing.

Thereafter, a via hole pattern is formed on the porous silica film 4 as the interlayer insulating film. Here, tri-level technology is used for the wiring trench pattern formed on the SiO_2 film 8.

More specifically, first, as shown in Fig. 2D, a lower resin film (organic film) 21 for making up the level difference of the SiO_2 film 8 to planarize the SiO_2 film 8 is formed. Then, an SOG (Spin On Glass) film (inorganic film) 22 to be used as a mask when the lower resin film 21 is etched is formed on the lower resin film 21. Subsequently, an organic ArF photoresist is applied on the SOG film 22, and then exposed and developed to thereby form a resist mask (photoresist film) 23 on which a via hole pattern is formed. The diameter of a via hole is, for example, approximately 100 nm.

Thereafter, as shown in Fig. 2E, the SOG film 22 is etched with the resist mask 23 as a mask. Then, the lower resin film 21 is etched with the SOG film

22 as a mask, and at the same time, the resist mask 23 is removed.

Subsequently, as shown in Fig. 2F, by etching the SiO₂ film 8, the SiC film 7, the SiO₂ film 6, and the SiC film 5 (four-layer hard mask) with the lower resin film 21 as a mask, the via hole pattern (second pattern) is formed on these films.

The etching of the SiO₂ film 8 is performed using the plasma etching device, for example, under the condition of 30 sccm of C₄F₆, 15 sccm of O₂, 300 sccm of Ar, 4.00 Pa (30 mTorr) of pressure, and 1000 W of RF source power.

The etching of the SiC film 7 is performed using the plasma etching device, for example, under the condition of 30 sccm of CH₂F₂, 20 sccm of O₂, 50 sccm of Ar, 50 sccm of N₂, 2.67 Pa (20 mTorr) of pressure, and 200 W of RF source power.

The etching of SiO₂ film 6 is performed using the plasma etching device, for example, under the condition of 20 sccm of C₄F₆, 15 sccm of O₂, 200 sccm of Ar, 4.00 Pa (30 mTorr) of pressure, and 1500 W of RF source power.

The etching of SiC film 5 is performed using the plasma etching device, for example, under the condition of 30 sccm of CH₂F₂, 20 sccm of O₂, 50 sccm of Ar, 50 sccm of N₂, 2.67 Pa (20 mTorr) of pressure, and 200 W of RF source power.

As a result of these series of etching, the via hole pattern (second pattern) is formed on the SiC film 7, the SiO₂ film 6, and the SiC film 5.

Then, as shown in Fig. 2G, the lower resin film 21 is removed by ashing.

Subsequently, as shown in Fig. 2H, the SiC films 7 and 5 are etched with the SiO₂ films 8 and 6 as a mask. This etching is performed using the plasma etching device, for example, under the condition of 30 sccm of CH₂F₂, 20 sccm of O₂, 50 sccm of Ar, 50 sccm of N₂, 2.67 Pa (20 mTorr) of pressure, and 200 W of RF source power. Consequently, the wiring trench pattern is formed on the SiC film 7, and the via hole pattern is formed on the SiC film 5.

Thereafter, as shown in Fig. 2I, the SiO₂ film 6 is etched with the SiC film 7 as a mask, the porous silica film 4 is etched with the SiC film 5 as a mask, and simultaneously the SiO₂ film 8 is removed. This etching is performed using the plasma etching device, for example, under the condition of 50 sccm of CF₄, 100 sccm of CHF₃, 50 sccm of Ar, 10 sccm of N₂, 26.7 Pa (200 mTorr) of pressure, and 1000 W of RF source power. A hole formed in the porous silica film 4 by this etching becomes a part of the via hole. Moreover, the wiring trench pattern is formed on the SiO₂ film 6.

Subsequently, as shown in Fig. 2J, an exposed portion of the SiC film 5 is removed by etching, and

at the same time, the SiC film 7 is thinned. This etching is performed using the plasma etching device, for example, under the condition of 30 sccm of CH_2F_2 , 15 sccm of O_2 , 50 sccm of Ar, 75 sccm of N_2 , 2.67 Pa (20 mTorr) of pressure, and 150 W of RF source power. As a result, the wiring trench pattern is formed on the SiC film 5.

Then, by etching the porous silica film 4 with the SiC film 7 as a mask, as shown in Fig. 2K, a wiring trench 25 is formed, and simultaneously a via hole 24 which reaches the SiC film 3 is formed. This etching is performed using the plasma etching device, for example, under the condition of 50 sccm of CF_4 , 100 sccm of CHF_3 , 50 sccm of Ar, 10 sccm of N_2 , 26.7 Pa (200 mTorr) of pressure, and 1000 W of RF source power.

Subsequently, as shown in Fig. 2L, an exposed portion of the SiC film 3 and the SiC film 7 are removed by etching. This etching is performed using the plasma etching device, for example, under the condition of 30 sccm of CH_2F_2 , 15 sccm of O_2 , 50 sccm of Ar, 75 sccm of N_2 , 2.67 Pa (20 mTorr) of pressure, and 150 W of RF source power. As a result of this etching, the via hole 24 gets to the lower Cu wiring 2.

Thereafter, as shown in Fig. 2M, a Cu film (wiring material) 26 is embedded in the wiring trench 25 and the via hole 24, and as shown in Fig. 2N, by

subjecting the Cu film 26 to CMP, a Cu wiring 27 is formed. Thereafter, an interlayer insulating film, a wiring, and the like are formed as required to complete the semiconductor device.

Fig. 3 is a sectional view showing the structure of the semiconductor device which is manufactured by applying the second embodiment thereto. In the example shown in Fig. 3, a multilayer wiring composed of at least two layers is formed by the manufacturing method according to the aforementioned embodiment. Moreover, a passivation film 31 made of SiN or the like is formed on the uppermost Cu wiring 27 and above the porous silica film 4. Further, a cover film composed of a SiO film 32 and a SiN film 33 is formed on the passivation film 31. An opening (not shown) for drawing out a pad as necessary is formed in the cover film.

Also in the aforementioned second embodiment, a hard mask is four-layer structured, and when the porous silica film 4 is etched, the SiC film 7, whose selection ratio to the porous silica film 4 is high, is used as a mask. Therefore, similarly to the first embodiment, deformation of the hard mask rarely occurs, which can prevent leakage caused by the deformation.

Note that a material for the interlayer insulating film is not particularly limited, and an organic low dielectric constant film may be used or a

silicon oxide film may be used. Moreover, instead of the silicon carbide film, for example, a silicon nitride film may be used as the etching stopper film. Instead of the silicon carbide film, a silicon nitride film or a silicon oxynitride film may be used as the first hard mask. Instead of the silicon carbide film, a silicon nitride film may be used as the third hard mask.

For example, when the silicon carbide film (SiC film) is used as the third hard mask and the silicon nitride film (SiN film) is used as the first hard mask, the silicon nitride film can be etched at a faster speed than the silicon carbide film, whereby a reduction in the thickness of the third hard mask when the first hard mask is etched can be suppressed. Hence, it becomes possible to make the third hard mask thinner. Consequently, the etching of the third hard mask with the fourth hard mask (SiO₂ film) is facilitated.

As described above in detail, according to the present invention, it is possible to process the interlayer insulating film with the first to fourth hard masks and, when the opening is formed, to ensure a high selection ratio between the hard mask and the interlayer insulating film. This makes it possible to obtain a wiring with a desired shape and thereby prevent leakage between wirings caused by miniaturization.

The present embodiments are to be considered in all respects as illustrative and no restrictive, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein. The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof.